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Intensive Short Rotation Culture of
Hybrid Poplar for Energy on Prince Edward Island

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Intensive Short Rotation Culture of Hybrid Poplar for Energy on Prince Edward Island

by

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ABSTRACT

In May 1981, a hybrid poplar experiment was established on Prince Edward Island. It consisted of two sites, combining two clones, three planting densities and four fertilizer levels. This report details the results of one year's growth on one site, and two years growth on the second, both on the four year old rootstock.

The highest one year production level was 8.27 ODT/ha on the Upton Road site with clone number 79, with a high planting density and no fertilizer. The highest two year production level was 12.12 ODT/ha with clone number 79, with a medium planting density and 400 kg of nitrogen fertilizer/ha. Soil and tissue analysis results are included.

Costs of production were calculated from this study, and were compared to the cost of production for biomass from natural stands. The production cost was lower for biomass from natural poplar stands ($19.12/ODT), than for the most economic cultivated stands ($53.16/ODT).

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INTRODUCTION

A recent study of energy alternatives for Prince Edward Island has identified wood energy as the most viable energy option for industrial institutional and residential space heat (Energy Mines and Resources, 1984). Presently, 264,000 cubic metres of wood are used for energy annually. This wood displaces 11,000,000 gallons of #2 fuel oil and saves the province an estimated $17.0 million per year. Intensively-managed, short rotation poplar culture is well suited to the agriculture heritage of the island and represents a potential source of wood energy. Specific objectives of this study were:

1. To determine maximum growth (tonnes/hectare) of two Populus x jackii clones under intensive culture from an existing coppice system;

2. To determine total and component biomass production (tonnes/hectare) under three density, and four fertilizer regimes;

3. To determine nutrient removal and soil nutrient depletion associated with a full-tree harvest;

4. To determine the cost per unit of biomass produced;

5. To assess the management system used and recommend improvements for future intensive production systems.

SITE DESCRIPTION

The study areas were located at the Provincial Forest Nursery on Upton Road, West Royalty, Queen's County (Lat. 46, 16', Long. 63, 11') and at Bristol, King's County (Lat. 46, 24', Long. 62 ,44') (Figure 1).

The Upton Road site is 2-5 metres above sea level (A.S.L), with a southwestern slope of less than 5%. A mixed-wood stand , dominated by white spruce (Picea glauca (Moench)Voss), white birch (Betula papyrifera Marsh.) and trembling aspen (Populus tremuloides Michx.) borders the experimental area on the north and northwest sides. Hedgerows of white spruce are to the east, south and southwest sides of the study area. The location has an average corn heat unit value of 2400 (MacDougall et. al., 1981).

The Bristol site is 125 metres ASL and is characterized by a southwest aspect with a maximim slope of 5%. To the south and west, the experimental area is surrounded by a mixed forest, with the dominant species being white spruce and trembling aspen. To the east and north, the study area borders on agricultural fields. The average corn heat unit value for this area is 2300 (MacDougall et. al., 1981).

The general climate of P.E.I. is cool and humid due to the influence of continental air masses and the moderating effect of the surrounding ocean. Precipitation is abundant, and evenly distributed through the year. The average frost-free period for the two sites is 150 days. The average January/February and June/July temperatures are -7 and +19 degrees Celsius respectively (MacDougall et.al., 1981).

FIGURE I. Site Locations

Soils in both study areas have a sandy loam texture, and tend to be moderately to strongly acidic. They have developed from glacial till, derived from red Pennsylvanian silt and sandstones. These soils have been classified as Orthic Humo-Ferric Podzols (Anon., 1978), and mapped as Charlottetown Series (MacDougall et. al., 1981).

Major soil management problems include:

1) high soil acidity with medium to low organic matter and low nutrient levels throughout the rooting zone;

2) restricted rooting depth;

3) high erodability (MacDougall et.al., 1981).

SITE HISTORY

Based on the initial soil analysis data, in the spring of 1981, phosphorus and potassium levels were adjusted before cultivation to recommended nursery standards by broadcast applications of triple superphosphate and muriate of potash.

At the Upton Road site, the soil was disced, plowed and subsoiled (d[illegible]n of 56 centimetres and distance between furrows of 122 centimetres). The area was then sprayed with Trifluralin, a pre-emergent herbicide at the rate of 2.1 litres/hectare and further cultivated with disc harrows to incorporate the Triflualin in the Ap horizon.

The Bristol site was treated with glyphosphate to remove the herbaceous/grass growth present. The site was rototilled to the depth of 15 centimetres.

On the basis of local performance and resistance to disease, two hybrid poplar clones from Ontario, identified as No's 44 and 79 in the P.E.I Forest Tree Nursery Register were selected for this study.

In the spring of 1981, each clone was planted in a square plot of 100 square metres. Between each plot a 6 metre buffer strip was planted with various other hybrid poplar clones. The trees were grown from unrooted cuttings at spacings of 1.25 by 1.25 metres, 0.6 by 1.0 metres and 0.3 by 1.0 metres which correspond to densities of 6400 (low), 16500 (medium) and 33000 (high) trees/hectare. Superimposed on density were four levels of nitrogen; 0 kg Nitrogen/ha (0N), 100 kg N/ha (1N), 200 kg N/ha (2N) and 400 kg N/ha (4N). The actual layout

of the two sites is illustrated in Figures 2 and 3. All stems were harvested at both sites in the fall of 1982 and 1983 (Miller pers. comm., 1985).

17 Clone 44 0.3 x 1.0 M ON/HA	9 Clone 44 0.6 x 1.0 M 2N/HA	1 Clone 44 0.6 x 1.0 M 4N/HA
18 Clone 79 1.25 x 1.25 M ON/HA	10 Clone 44 1.25 x 1.25 0N/HA	2 Clone 79 0.3 x 1.0 M 0N/HA
19 Clone 44 0.3 x 1.0 M 1N/HA	11 Clone 44 0.6 x 1.0 M 1N/HA	3 Clone 44 0.3 x 1.0 M 2N/HA
20 Clone 79 0.3 x 1.0 M 2N/HA	12 Clone 79 0.6 x 1.0 M 0N/HA	4 Clone 79 0.6 x 1.0 M 4N/HA
21 Clone 44 1.25 x 1.25 M 1N/HA	13 Clone 44 0.6 x 1.0 M 0N/HA	5 Clone 79 1.25 x 1.25 M 1N/HA
22 Clone 79 0.6 x 1.0 M 1N/HA	14 Clone 79 0.3 x 1.0 M 4N/HA	6 Clone 44 1.25 x 1.25 M 4N/HA
23 Clone 44 1.25 x 1.25 M 2N/HA	15 Clone 79 1.25 x 1.25 M 2N/HA	7 Clone 44 0.3 x 1.0 M 4N/HA
24 Clone 79 0.3 x 1.0 M 1N/HA	16 Clone 79 0.6 x 1.0 M 2N/HA	8 Clone 79 1.25 x 1.25 M 4N/HA

Figure 2: Randomized Plot Layout For Upton Road Site.

1 Clone 79 1.25 x 1.25 M 4N/HA	7 Clone 44 1.25 x 1.25 M 4N/HA	13 Clone 79 0.3 x 1.0 M 1N/HA	19 Clone 44 0.6 x 1.0 M 0N/HA
2 Clone 44 0.3 x 1.0 M 0N/HA	8 Clone 44 0.6 x 1.0 M 1N/HA	14 Clone 79 0.6 x 1.0 M 2N/HA	20 Clone 79 0.6 x 1.0 M 0N/HA
3 Clone 79 0.3 x 1.0 M 4N/HA	9 Clone 79 1.25 x 1.25 M 1N/HA	15 Clone 44 0.3 x 1.0 M 1N/HA	21 Clone 44 1.25 x 1.25 M 1N/HA
4 Clone 79 1.25 x 1.25 M 2N/HA	10 Clone 79 0.3 x 1.0 M 0N/HA	16 Clone 44 1.25 x 1.25 M 2N/HA	22 Clone 79 0.6 x 1.0 M 1N/HA
5 Clone 79 0.3 x 1.0 M 2N/HA	11 Clone 44 0.3 x 1.0 M 4N/HA	17 Clone 44 0.3 x 1.0 M 2N/HA	23 Clone 44 1.25 x 1.25 M 0N/HA
6 Clone 79 0.6 x 1.0 M 4N/HA	12 Clone 44 0.6 x 1.0 M 4N/HA	18 Clone 44 0.6 x 1.0 M 2N/HA	24 Clone 79 1.25 x 1.25 M 0N/HA

Figure 3: Randomized Plot Layout For Bristol Site.

EXPERIMENTAL PROCEDURE

Soil samples were taken in May 1984 from a composite sample consisting of 20 soil probes per plot. Subsamples were labelled and sent to the Prince Edward Island Department of Agriculture Soil Testing Laboratory in Charlottetown for analysis.

Stems on root stocks at the Upton Road site were harvested in May, 1984, in order to produce one-year growth data on a four-year-old root stock. The Bristol site was not harvested, producing two-year growth data on a four-year-old root stock.

Fertilizer was applied manually to the plot, in the form of ammonium nitrate: once before bud burst, and in three additional, equal monthly applications. The four fertilizer levels were 400 kg/ha, 200 kg/ha, 100 kg/ha, and 0 kg/ha.

Competition control was achieved, when necessary, by the use of paraquat, at a rate of 5.5 litres/ha. To avoid herbicide drift and damage to the hybrid poplar shoots, plastic shields were affixed to the nozzles of the backpack sprayers. Due to the height of competition, the Upton Road site was manually weeded on one occassion. Dutox was applied at the recommended rate by a mist blower, to control aphids.

At the end of the growing season, soil sampling was repeated. The total and component biomass production (ODT/ha) under the three density and four fertilizer regimes were determined. Nutrient analysis was conducted on both stem and foliage samples at the end of the growing season (see Measurement Procedure). The various treatments and applications dates are shown in Table 1.

Table 1. Treatments and treatment dates.

	Site	
	Hurry Road	Bristol
Biomass Harvest	May 16-18	-
Soil Samples	May 20	May 21
Fertilizer #1	May 27	May 31
Fertilizer #2	July 4	June 28
Fertilizer #3	July 26	July 26
Fertilizer #4	August 27	August 28
Competition Control	July 20-23	June 8
	August 27*	June 21*
		August 17*
Aphid Control	July 27*	August 17*
	August 28*	
Biomass Harvest	Sept.21-Oct.5	Sept.22-29
Soil Samples	October 11	October 12

* only plots requiring control treated.

MEASUREMENT PROCEDURE

The total and component biomass production (ODT/ha) were determined from a number of field measurements. The total height and basal diameters were taken on all stems of six root stocks per plot. The rootstocks were selected using a computer program, which chose random numbers less than or equal to the number of rootstocks per plot. The total number of rootstocks per plot is shown in Appendix I. The height and basal diameter were measured at 30 centimetres above ground. The distribution of height and basal diameter was used to select 30 stems per plot which in turn, were sampled to develop the weight relationships.

Thirty stems per plot were harvested at 30 centimetres above the ground, and the basal diameter of each stem was measured at this point to the nearest 0.01 centimetre. Each stem, including leaves, was weighed to the nearest 0.01 gram on a Mettler PC 2000 balance. Composite stem and leaf samples were taken for each plot to be used in a nutrient analysis. All samples not utilized immediately were stored at 0 degrees Celsius to prevent mold formation. Stem and leaf subsamples were taken from each of 48 plots for ovendry weight determination. Of these, 17 were dried at 105 degrees Celsius in a Fisher Econotemp Laboratory Oven Model 55G for 24 hours. The remaining samples (31 plots) were dried at 105 degrees Celsius for 24 hours in the Faculty of Forestry's Wood Drying Kiln at the University of New Brunswick. No difference in average moisture contents was noted between the two drying methods . The total, subsample green and dry weights of the stem and leaves were recorded and utilized to

produce the weight relationships. The stem and foliar nutrient analysis samples were dried for 48 hours at 70 degrees Celsius in the laboratory ovens and sent to the Prince Edward Island Department of Agriculture Soil Testing Laboratory for analysis.

DATA COMPILATION AND RESULTS

Biomass Production

The basal diameter and height obtained from each of the 48 plots were used to produce height/diameter relationships. These relationships were utilized to generate the heights for the 30 stems sampled for the biomass production calculation.

For each of the 48 plots, a computer data file was established for height (as determined by the height/diameter relationship), diameter, total green weight of leaves and stems, subsample green weight, and subsample oven-dry weight of leaves and stems. Using the Statistical Package for the Social Sciences (SPSS) , the green and oven-dry total and component production coefficients were generated (Appendix II):

W(woody fibre) = a+bH(D**2)

W(leaves) = a+bH(D**2)

W(total) = a+bH(D**2)

- where D is basal diameter
- where W is oven dried weight
- where H is height of the stem
- where a and b are regression coefficients.

These relationships were utilized in a computer program, to produce the one-year oven-dry production figures for Upton Road (Table 2), and the total two year oven-dry production figures for Bristol (Table 3). The best production levels for each site are shown in Figures 4 and 5.

Table 2. One year component and total biomass production at Upton Road.

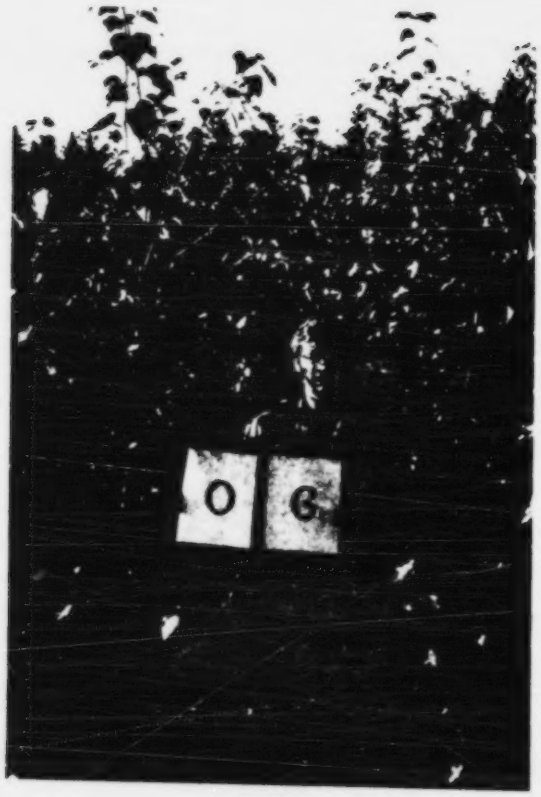
				ODT/Ha		
Plot#	Clone#	Density	Fertilizer	Leaf	Stem	Total
1	44	M	4N	2.78	3.36	6.14
2	79	H	0N	3.58	4.69	8.27
3	44	H	2N	1.71	2.40	4.11
4	79	M	4N	2.41	4.65	7.06
5	79	L	1N	1.51	2.02	3.53
6	44	L	4N	1.21	1.25	2.46
7	44	H	4N	2.07	3.25	5.32
8	79	L	4N	2.00	4.03	6.02
9	44	M	2N	1.56	2.26	3.82
10	44	L	0N	1.83	1.93	3.76
11	44	M	1N	2.37	2.70	5.07
12	79	M	0N	2.12	3.00	5.12
13	44	M	0N	3.32	3.15	6.47
14	79	H	4N	2.40	4.80	7.20
15	79	L	2N	1.21	2.33	3.54
16	79	M	2N	2.44	5.80	8.24
17	44	H	0N	1.83	2.61	4.44
18	79	L	0N	0.72	1.07	1.79
19	44	H	1N	2.02	3.21	5.23
20	79	H	2N	1.86	4.69	6.55
21	44	L	1N	1.78	2.21	4.00
22	79	M	1N	0.97	1.56	2.53
23	44	L	2N	2.04	2.85	4.89
24	79	H	1N	1.94	4.87	6.81

Table 3. Two year component and total biomass production at Bristol.

				ODT/Ha/Year		
Plot#	Clone #	Density	Fertilizer	Leaf	Stem	Total
1	79	L	4N	0.42	0.94	1.37
2	44	H	0N	1.13	2.92	4.05
3	79	H	4N	1.11	3.21	4.32
4	79	L	2N	0.85	1.91	2.76
5	79	H	2N	1.97	7.53	9.50
6	79	M	4N	3.36	8.76	12.12
7	44	L	4N	1.22	2.51	3.73
8	44	M	1N	1.28	6.07	7.35
9	79	L	1N	0.81	2.09	2.90
10	79	H	0N	0.64	2.52	3.16
11	44	H	4N	2.04	4.29	6.33
12	44	M	4N	2.73	4.68	7.40
13	79	H	1N	0.82	5.52	6.34
14	79	M	2N	1.41	6.12	7.52
15	44	H	1N	1.38	5.02	6.40
16	44	L	2N	0.62	0.97	1.59
17	44	H	2N	1.76	3.63	5.39
18	44	M	2N	3.66	6.09	9.76
19	44	M	0N	1.05	3.99	5.04
20	79	M	0N	0.55	3.68	4.23
21	44	L	1N	0.27	0.45	0.73
22	79	M	1N	0.81	2.79	3.60
23	44	L	0N	0.51	0.83	1.34
24	79	L	0N	0.52	1.36	1.88

Figure 4. Best production level Upton Road plot #2.

Figure 5. Best production level Bristol plot #6.



Soil Analysis

The soil analysis were carried out by the Soil Testing Laboratory of the P.E.I. Department of Agriculture, utilizing standard laboratory procedures.

Results of sampling before and after the growing season are shown in Appendix III for both sites.

Nutrient Analysis

The composite stem and leaf samples from harvested stems were analysed by the Soils and Feed Testing Laboratory of the Department of Agriculture. Stem sample results for the two sites are presented in Appendix IV and include nitrogen, phosphorus, potassium, calcium and magnesium content. The leaf samples were analyzed only for nitrogen content (Appendix IV).

DISCUSSION

Total Biomass Production

The total oven dry biomass production for the two sites is shown on Tables 4 & 5.

A two-way analysis of variance was carried out on these figures utilizing a SPSS program (ANOVTPRO). The result of this analysis showed significant differences (95% confidence level) only for the three planting densities and the two sites.

The production levels by planting density and fertilizer levels are presented in Figures 6 and 7 for Upton Road and Figures 8 and 9 for the Bristol site.

The observed differences between nitrogen levels were not significant. However, over a longer rotation, the effect of nitrogen would probably become more pronounced.

The differences between sites and planting densities were expected, based on the previous study utilizing these coppice systems (Miller, 1985).

The two sites, while situated on soils of the same classification series, produced significantly different results. These differences may be due to subsoiling at the Upton Road site, which increased rooting depth or more probably, the exposure of the Bristol site. It was noted that natural stands of white spruce and trembling aspen in both locations reflect a similar pattern of growth to that of the hybrid poplar.

The planting density with the highest production rate

Table 4. Total one year biomass production at Upton Road in oven dry tonnes per hectare.

PRODUCTION (ODT/HA) ROOT STOCK DENSITY / CLONE	LOW 79	LOW 44	MEDIUM 79	MEDIUM 44	HIGH 79	HIGH 44	MEANS 79	MEANS 44	MEAN FERT.
FERTILIZER									
NO NITROGEN	1.79	3.76	5.12	6.47	8.27	4.44	5.06	4.89	4.98
100 KG/HA NITROGEN	3.53	4.00	2.53	5.07	6.81	5.23	4.29	4.77	4.53
200 KG/HA NITROGEN	3.54	4.89	8.24	3.82	6.55	4.11	6.11	4.27	5.19
400 KG/HA NITROGEN	6.02	2.46	7.06	6.14	7.20	5.32	6.76	4.64	5.70
MEANS CLONE	3.72	3.78	5.74	5.38	7.21	4.78	5.55	4.64	
MEANS DENSITY	3.75		5.56		6.00		5.10		

Table 5. Total two year biomass production at Bristol in oven dry tonnes per hectare.

ROOT STOCK DENSITY	LOW		MEDIUM		HIGH		MEANS		MEAN
CLONE	79	44	79	44	79	44	79	44	FERT.
FERTILIZER									
NO NITROGEN	1.88	1.34	4.23	5.04	3.16	4.05	3.09	3.48	3.28
100 KG/HA NITROGEN	2.90	0.73	3.60	7.35	6.34	6.40	4.28	4.83	4.55
200 KG/HA NITROGEN	2.76	1.59	7.52	9.74	9.50	5.39	6.59	5.58	6.08
400 KG/HA NITROGEN	1.37	3.73	12.12	7.40	4.32	6.33	5.94	5.82	5.88
MEAN CLONE	2.23	1.85	6.87	7.39	5.83	5.54	4.97	4.92	
MEAN DENSITY	2.04		7.13		5.69		4.95		

FIGURE 6. UPTON ROAD ONE YEAR TOTAL AND COMPONENT BIOMASS PRODUCTION BY PLANTING DENSITY.

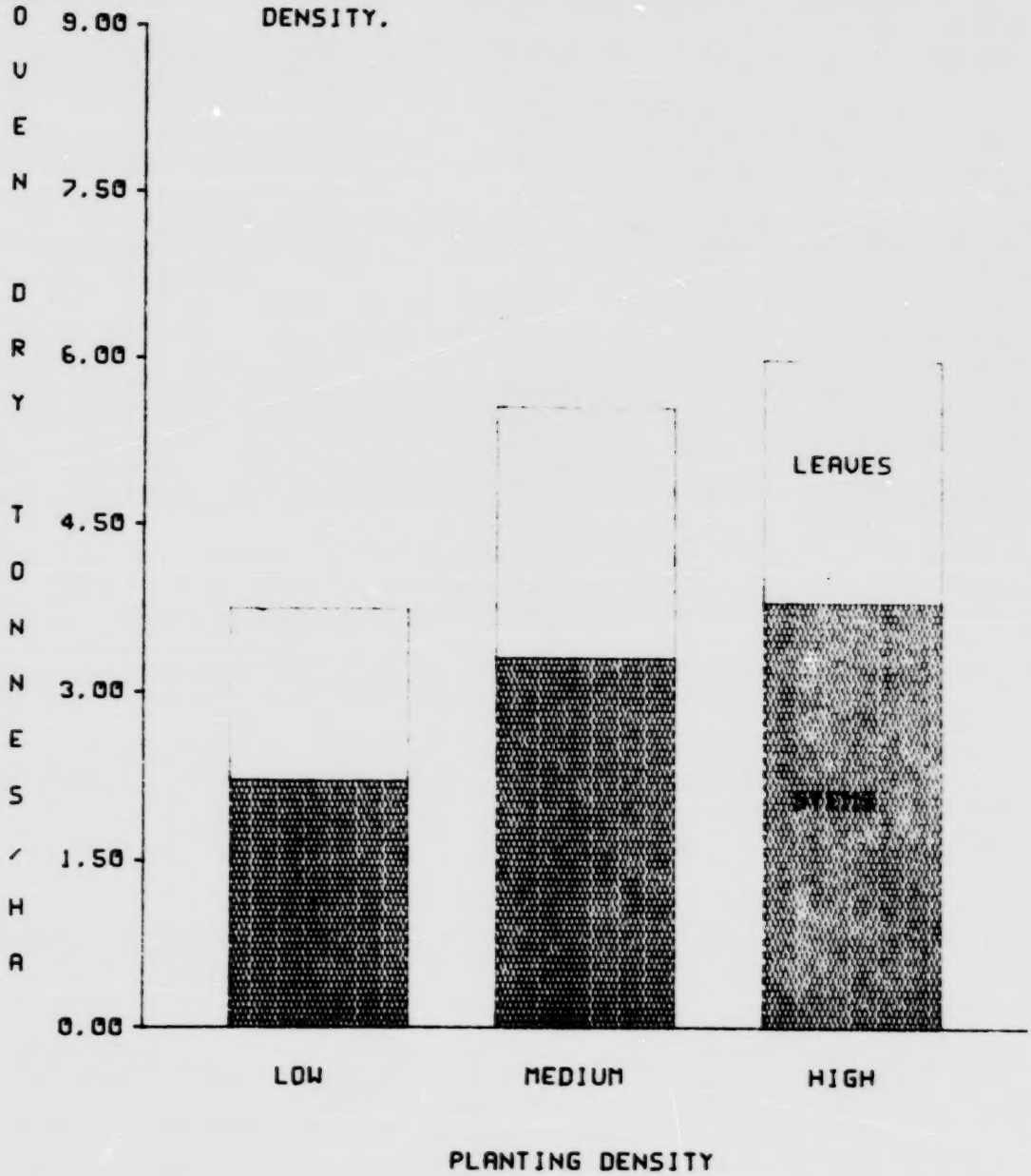


FIGURE 7. UPTON ROAD ONE YEAR TOTAL AND COMPONENT BIOMASS PRODUCTION BY FERTILIZER LEVEL.

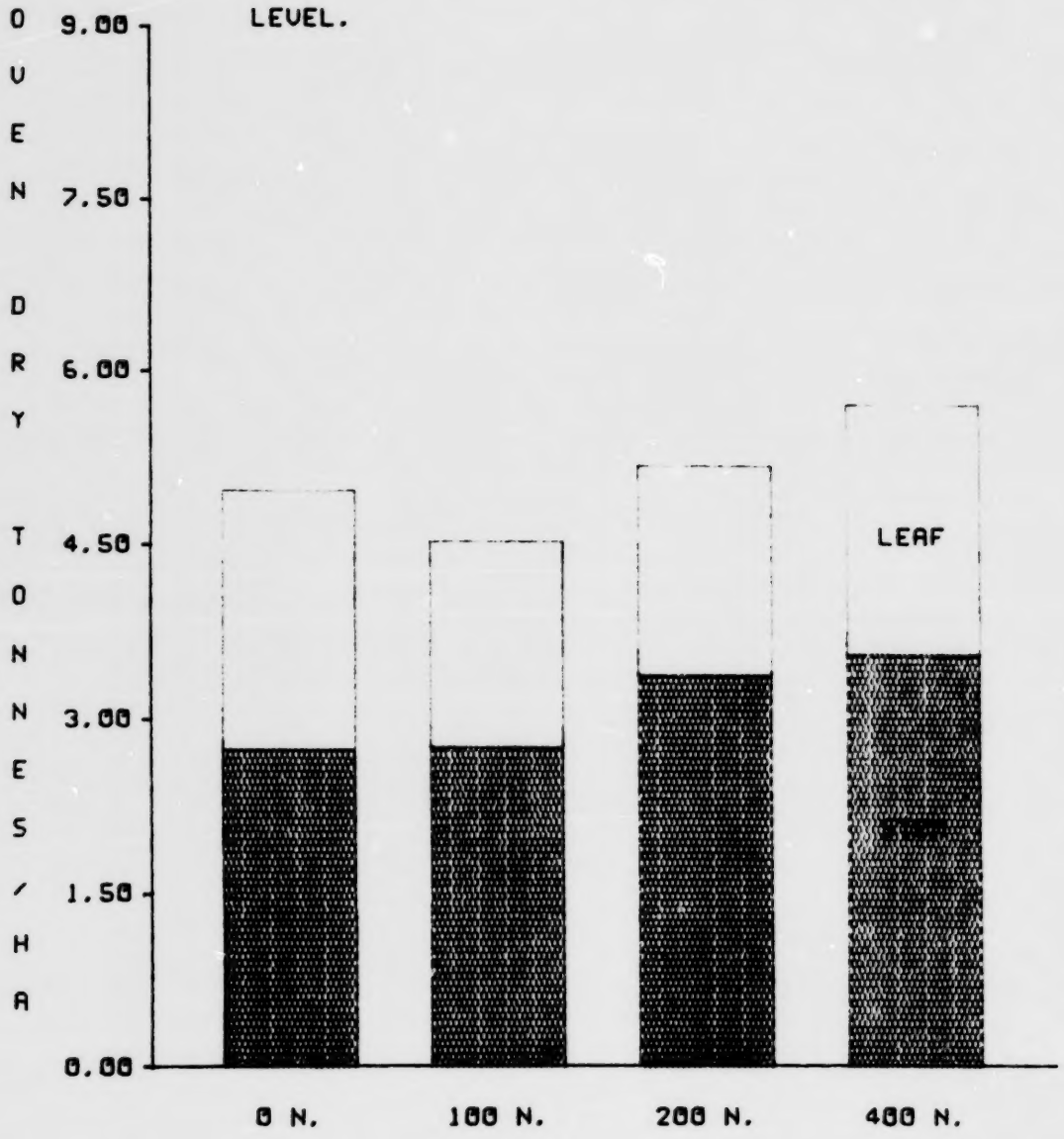


FIGURE 8. BRISTOL TWO YEAR TOTAL AND COMPONENT BIOMASS BY PLANTING DENSITY.

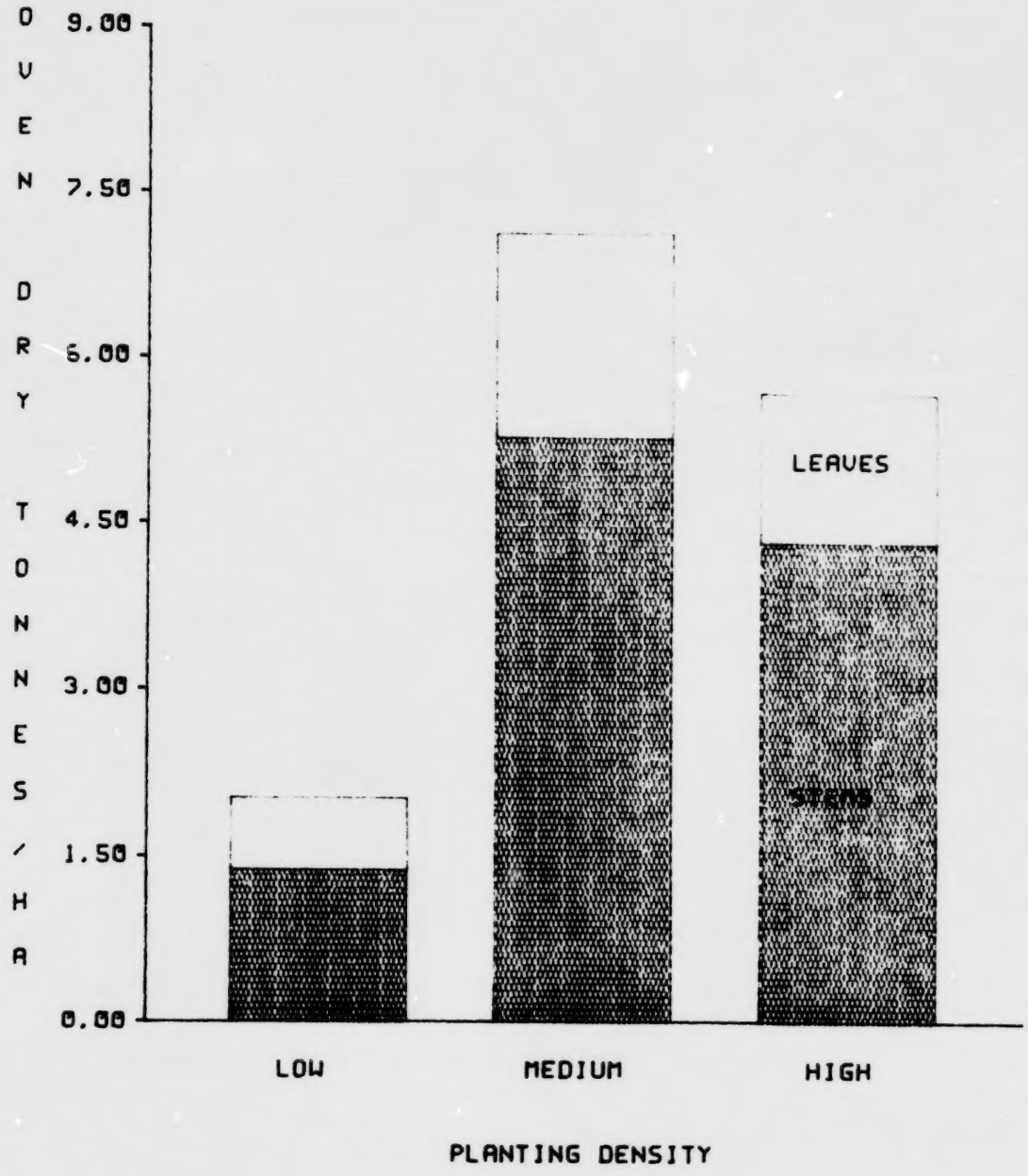
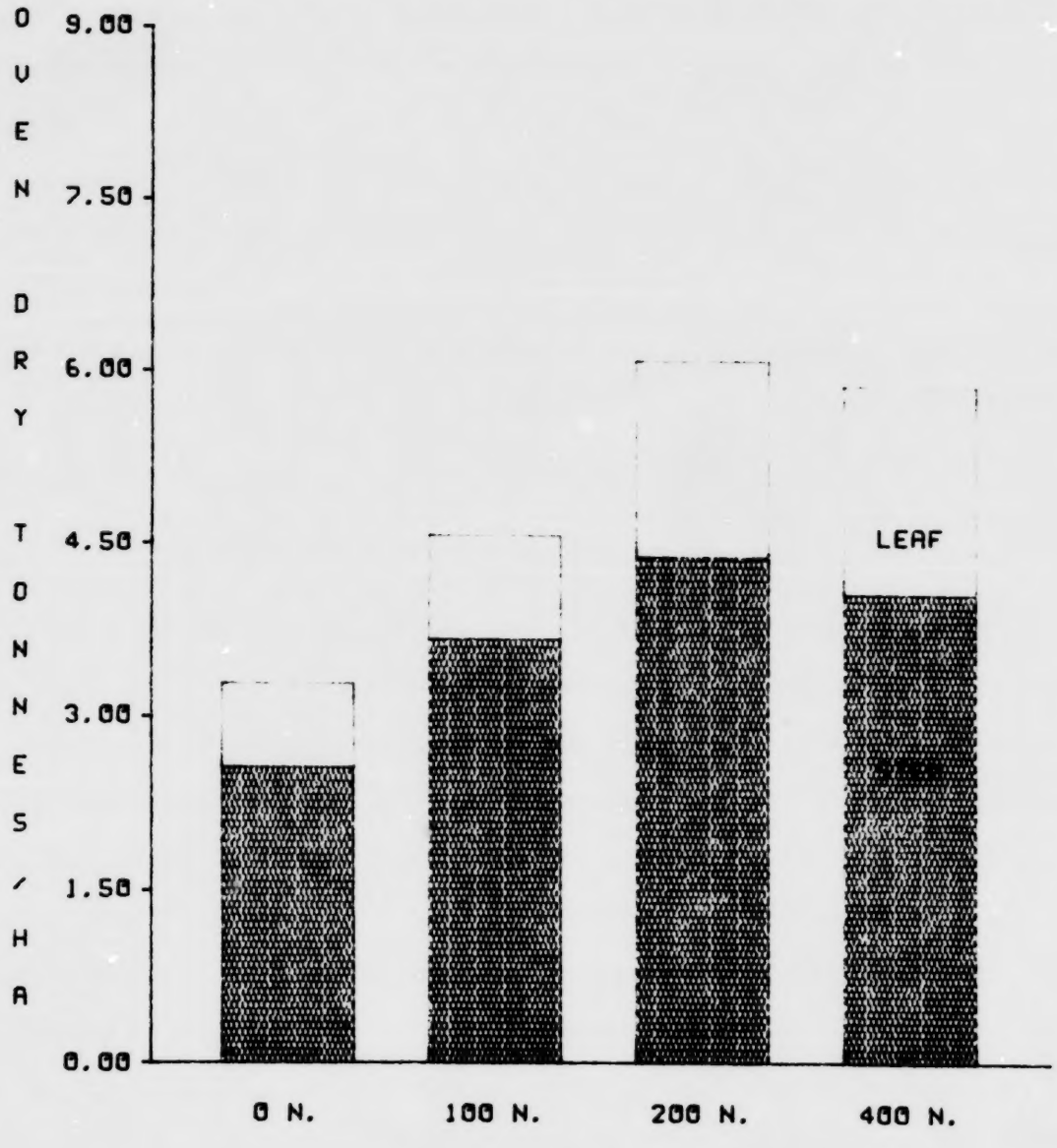


FIGURE 9. BRISTOL TWO YEAR TOTAL AND COMPONENT BIOMASS PRODUCTION BY FERTILIZER LEVEL.



differed between the two sites, although site/density interactions were not significant. The highest production (one-year-old) at the Upton Road site was at the high planting density while the medium density was highest at the Bristol site (two-year-old). It is probable that the medium or lower planting densities would produce higher total yields, in a rotation longer than one year, due to the expected high mortality of stems at the higher planting density. This assumption was confirmed by the number of stems per root stock encountered during the diameter/height relationship determination.

Stem Wood Biomass Production

Means tables (Tables 6 & 7) have been constructed for the stem-branch component of the tree. The highest stem-wood production from both sites was obtained with clone # 79 at medium planting density. The corresponding fertilizer treatment was 200 kg/ha at Upton Road (one-year production) and 400 kg/ha at the Bristol site (two-year production).

An analysis of variance was performed on the stem-wood production and, as with total biomass, only site, clone and density totals were significantly different at a 95% confidence level. The absence of significant fertilizer levels was unexpected, as with the total biomass production results.

The combination of clone #79, medium planting density and 200 kg/ha of nitrogen has been used for the cost of production scenarios, since it is with this regime the greatest volume of

Table 6. Stem one year biomass production at Upton Road in oven dry tonnes per hectare.

PRODUCTION (ODT/HA) ROOT STOCK									
DENSITY	LOW		MEDIUM		HIGH		MEANS		FERT.
CLONE	79	44	79	44	79	44	79	44	MEAN
FERTILIZER NO NITROGEN	1.07	1.93	3.00	3.75	4.69	2.61	2.92	2.56	2.74
100 KG/HA NITROGEN	2.02	2.21	1.56	2.70	4.87	3.21	2.82	2.71	2.76
200 KG/HA NITROGEN	2.33	2.85	5.80	2.23	4.69	2.40	4.27	2.49	3.38
400 KG/HA NIROGEN	4.03	1.25	4.65	3.36	4.80	3.25	4.49	2.62	3.56
MEANS DENSITY BY CLONE	2.36	2.06	3.75	2.86	4.76	2.87	3.36	2.60	
MEANS DENSITY	2.21		3.31		3.82		3.11		

Table 7. Stem two year biomass production at Bristol in oven dry tonnes per hectare.

PRODUCTION (ODT/HA) ROOT STOCK DENSITY	LOW		MEDIUM		HIGH		MEANS		FERT.
CLONE	79	44	79	44	79	44	79	44	MEAN
FERTILIZER NO NITROGEN	1.36	0.83	3.68	3.99	2.52	2.92	2.52	2.58	2.55
100 KG/HA NITROGEN	2.09	0.45	2.79	6.07	5.52	5.02	3.47	3.85	3.65
200 KG/HA NITROGEN	1.91	0.97	6.12	6.09	7.53	3.63	5.19	3.56	4.38
400 KG/HA NITROGEN	0.94	2.51	8.76	4.68	3.21	4.29	4.30	3.83	4.07
MEANS DENSITY BY CLONE	1.58	1.19	5.34	5.21	4.70	3.97	3.87	3.46	
MEANS DENSITY	1.39		5.28		4.34		3.67		

stem/branch wood was produced, based on the two-year results from the Bristol site.

Soil Analysis

Tables 8 and 9 show changes in soil nutrients over the term of the experiment. With the exception of nitrogen, which was added to both sites during the growing season and, potash and calcium on the Upton Road site, there is a decline in all mean nutrient levels.

When an analysis of variance is performed, the only significant correlations at a 95% confidence level are site/magnesium, site/potash, site/calcium and site/nitrogen. However, since the two sites were different at the beginning of the experiment, all site/nutrient relationships can be ignored (Miller, 1985). The result, is that while nutrient levels are generally depleted there is no correlation with any specific treatment, either with respect to clone, planting density or fertilizer level.

The growing of hybrid poplar does result in soil nutrient depletion and, if growth rates are to be maintained, soil nutrient levels must be supplemented.

Nutrient Uptake

An analysis of variance was performed on the stem dry nutrient concentrations. A number of nutrient concentrations were

Table 8. Changes in soil nutrients at Upton Road site.
(After - Before = Change)

Plot-Clone-Density-Fertilizer	pH	Phosphate (ppm)	Potash (ppm)	Calcium (ppm)	Magnesium (ppm)	Nitrogen (%)
1-44-M-4N	-0.5	-101	-3	-41	-3	-2
2-79-H-0N	-0.1	-112	+5	-1	-2	-1
3-44-H-2N	+0.1	-94	+33	+70	+19	-3
4-79-M-4N	-0.3	-133	+27	+28	+10	-2
5-79-L-1N	-0.3	-98	-1	-47	-5	-1
6-44-L-4N	-1.0	-82	+6	-91	-10	+2
7-44-H-4N	-0.3	-80	+16	-47	+3	+3
8-79-L-4N	-0.9	-91	-5	-78	-12	+5
9-44-M-2N	-0.5	-123	-6	-54	-18	+3
10-44-L-0N	-0.3	-89	-17	-38	-16	+3
11-44-M-1N	-0.3	-78	+12	-11	-7	+7
12-79-M-0N	-0.9	-102	-12	-174	-31	+3
13-44-M-0N	-0.4	-125	-27	-35	-16	+3
14-79-H-4N	-0.3	-139	+47	+62	+12	+3
15-79-L-2N	-0.2	-96	+16	+102	-14	+3
16-79-M-2N	-0.2	-70	+12	+49	+8	+2
17-44-H-0N	-0.2	-117	+22	+80	+11	-4
18-79-L-0N	-0.2	-129	+35	+81	+11	+1
19-44-H-1N	-0.2	-117	-12	+22	+4	+1
20-79-H-2N	-0.2	-114	+25	+86	+17	+3
21-44-L-1N	-0.2	-111	+21	+53	-3	0
22-79-M-1N	-0.1	-133	+19	+89	+7	+1
23-44-L-2N	-0.1	-114	+9	+28	+2	+2
24-79-H-1N	-0.4	-101	+49	+16	+2	+1

* example of code 1-44-M-4N
  1-plot #
  44-clone #
  M-medium density
  4N-400kg/ha nitrogen

Table 9. Changes in soil nutrients at the Bristol site.
(After - Before = Change)

Plot-Clone-Density-Fertilizer	pH	Phosphate (ppm)	Potash (ppm)	Calcium (ppm)	Magnesium (ppm)	Nitrogen (%)
1-79-L-4N	-0.3	-93	-37	-30	-13	-2
2-44-H-0N	-0.1	-48	-19	-31	-12	-5
3-79-H-4N	-0.4	-52	-32	-110	-35	-5
4-79-L-2N	-0.1	-53	-64	-100	-26	-6
5-79-H-2N	-0.3	-60	-64	-27	-6	-4
6-79-M-4N	-0.7	-48	-54	-66	-18	-7
7-44-L-4N	-0.4	-81	+4	+182	-7	-2
8-44-M-1N	-0.1	-72	-71	-29	-6	-3
9-79-L-1N	-0.4	-68	-60	-110	-32	-7
10-79-H-0N	-0.2	-74	-35	-11	+4	-4
11-44-H-4N	-0.6	-54	-71	-99	-26	-3
12-44-M-4N	-0.4	-54	-66	-100	-16	+1
13-79-H-1N	+0.1	-59	-43	-48	-13	0
14-79-M-2N	-0.2	-142	-66	-151	-39	+1
15-44-H-1N	-0.2	-275	-63	-83	-28	0
16-44-L-2N	-0.1	-257	-83	-74	-21	0
17-44-H-2N	-0.3	-186	-51	-173	-39	+2
18-44-M-2N	-0.4	-75	-46	-27	-16	0
19-44-M-0N	-0.5	-332	+38	-36	-54	+7
20-79-M-0N	-0.4	-262	-26	-5	-47	+3
21-44-L-1N	0.0	-152	-77	-96	-24	-3
22-79-M-1N	-0.5	-139	-4	+69	-49	+2
23-44-L-0N	0.0	-209	-48	-96	-15	-1
24-79-L-0N	-0.5	-192	+15	+1	-66	+2

found to be significant at the 95% confidence level. The significan site interactions were site/potash, site/calcium and site/ph. As previously stated, these relationships can be ignored due to the differences in sites prior to this experiment. Other significant correlations found were fertilzer/ph, fertilizer/ calcium, planting density/potash and density/phosphate.

The mean foliar dry nutrient concentrations (%) were calculated as: 0.21 for phosphorous, 1.79 for potash, 1.09 for calcium, 0.36 for magnesium by Miller and Krause (1983). Their analysis of variance conducted resulted in significant differences in site/calcium, site/magnesium and density/ magnesium. However, due to the differences in the two sites at the beginning of this study, all site nutrient relationships can be ignored (Miller, 1985). The significant difference in density/magnesium correlation was unexpected since density of plantations have little, if any, effect on foliar nutrient concentrations (Bernier, 1984).

The foliar nitrogen concentration was calculated as 1.96% in this study. An analysis of variance was conducted resulting in significant differences at a 95% confidence level observed in clone and fertilizer levels. These differences were expected since clonal differences in intensively-grown plantation hybrid poplars have been reported as causing wide variations in foliar nutrient levels (Bernier, 1984).

In conclusion, nutrient depletion results from growing hybrid poplar. This depletion could be partially compensated by

the recycling of nutrients from the leaves by harvesting after leaf-fall. The term of this study did not permit a determination of long-range nutrient recycling.

COSTS OF PRODUCTION

Three scenarios were examined to determine the cost of producing one oven dry tonne of stem biomass. The assumption is made that the production levels of plantations will approximate the best result and experience from this study,therefore scenarios 1 and 2 utilize the following prescriptions.

Planting of clone #79 at medium density (16500 stems/ha) and fertilization with nitrogen, at a rate of 200 kg/ha. Prior to planting, site preparation by plowing , subsoiling and harrowing, and fertilization at 280 kg/ha of 10:10:10 is recommended. In order to provide competition control, the rows should be covered with a synthetic mulch prior to planting. This synthetic mulch will control vegetation for two years, after which the poplar itself should control any competion through canopy closure. To aid in fertilization and insect control, 4-5 metre wide lanes should be left every 24 metres.

Scenario 1

In this scenario, a plantation was established utilizing clone #79, at medium density, fertilized with 200 kg/ha of nitrogen per year. The factors in determining the cost per oven dry tonne of stem biomass included: Class III Agricultural land rental, site preparation, pre-planting fertilization, planting stock, planting, competition control, post-planting fertilization and insect control. The cost assumptions are presented in table

10 and Table 11 provides a breakdown of the costs associated with this scenario.

Scenario 2

This scenario also involves a plantation of clone #79, medium density, fertilized at a rate of 200 kg/ha of nitrogen fertilizer per year. The cost of producing an oven dry tonne of stem biomass is significantly lower, due to subsidies from the Canada P.E.I. Forest Resource Development Agreement, Private Woodlot Management Program. These factors include: Class III Agricultural land rental, pre-planting fertilization, post-planting fertilization and insect control. The cost assumptions are the same as in scenario 1 (Table 10). Table 12 provides a breakdown of costs associated with this scenario.

Scenario 3

The natural poplar resource was used to produce the biomass in this scenario. Based upon a 25 year rotation and an annual production 3.36 ODT/Ha of harvestable biomass (Glen, 1985). To provide compatability with scenario's 1 and 2, the leaf component was excluded. The use of component biomass equations (Ker, 1980) resulted in annual production of 3.23 ODT/ha/yr of natural poplar biomass. Table 13 provides a breakdown of costs associated with this scenario.

Table 10. Cost assumptions.

Land Cost
- Class III agricultural land $123.55/ha
- Forest land $61.78/ha
- based on land rental rates quoted by the P.E.I. land Developement Corporation

Site Preperation
- $125.00/ha, includes ploughing, subsoiling, harrowing
-based on Federal Resource Developement Agreement (FRDA)

Preplanting fertilizer
- 280 kg/ha of 10:10:10 at $220.00/tonne at $61.60/ha
- spreading at $23.10/ha
- total cost $84.70/ha
- based on costs developed by the J.F. Gaudet Tree Nursery

Cost of Planting Stock
- $50.00/1000 seedlings for non-rooted cuttings
- based on production figures from J.F. Gaudet Tree Nursery

Cost of Planting
- $70.00/1000 seedlings
-based on production figures from J.F. Gaudet Tree Nursery

Competition Control
- utilizing .61 meter wide plastic mulch and application cost of $419.40
- based on figures from J.F. Gaudet Tree Nursery and assuming two year control is provided

Post Planting Fertilizer
- 200/kg of nitrogen/ha/year at a cost of $0.34/kg which equals $68.00/ha and a spreading cost of $23.10/ha totaling $91.10/ha

Insect Control
- cost of $5.17/ha
- application rate of $18.71/hour x 2 hours/ha = $37.42/ha
- two applications per year $42.49 x 2 = $85.18/ha

Table 11. Factors involved in production costs for Scenario 1.

Establishment Year	Cost ($/Ha)
Land rental	123.55
Site preparation	125.00
Pre-planting fertilization	84.70
Stock and planting	1980.00
Competition control	419.40
Post-planting fertilization	91.10
Insect control	85.18
	2908.93
Subsequent Years	
Land rental	123.55
Post-planting fertilization	91.10
Insect control	85.18
	299.83

Table 12. Factors involved in production costs for Scenario 2.

Establishment Year	Cost ($/Ha)
Land rental	123.55
Post-planting fertilization	91.10
Insect control	85.18
	384.53
Subsequent Years	
Land rental	123.55
Post-planting fertilization	91.10
Insect control	85.18
	299.83

Table 13. Factors involved in production costs for Scenario 3.

Establishment Year	**Cost ($/Ha)**
Land rental	61.78
	61.78
Subsequent Years	
Land rental	61.78
	61.78

Production Cost

An examination of the cost per oven dry tonne on 2, 5 and 10 year rotation for the three senarios (Table 14) suggests that natural poplar provides the most economic source of stem biomass at $19.12 per oven dry tonne.

Unless the value of biomass increases significantly, hybrid poplar plantations are not economical; $53.16/ODT for the subsidized scenario vs $19.12/ODT for the existing natural resource. However, to assume continued subsidization through the Forest Resource Development Agreement Private Woodlot Management Program for energy plantations is unrealistic, when a large, under-utilized resource exists. Without subsidization, the cost of producing an oven dry tonne of biomass from a hybrid poplar plantation increases to $96.68, on a 10-year rotation.

If the value of biomass does increase, it may be more cost-effective to increase management input in natural stands, as compared to plantations.

Table 14. Costs per oven dry tonne of stem biomass for the three scenarios.

	Rotation Length Years	Estimated Yield ODT/ha	Cost/Ha $	Cost/ODT $
SCENARIO 1	2	11.6	3208.76	276.62
	5	29.0	4108.25	141.66
	10	58.0	5607.40	96.68
SCENARIO 2	2	11.6	684.36	59.00
	5	29.0	1583.85	54.62
	10	58.0	3083.00	53.16
SCENARIO 3	25	80.8	1544.50	19.12

SUMMARY

The experiment envolved the determination of the growth of two hybrid poplar clones growth at three planting densities and with four levels of nitrogen fertilizer. The work was a continuation of an experiment established in 1981. The two sites had been harvested prior to the commencement of this study, resulting in second rotation data being produced from four year old root stock.

The maximum production rate obtained was 8.27 ODT's/ha/yr. Only site and planting density produced significant differences in the total and stem biomass production.

The soil analysis results show a decline in all soil nutrient levels. The effects of this decline can be reduced by harvesting after leaf fall, thus permitting some nutrient recycling.

Costs of biomass have been calculated for the highest production treatment obtained by this study and for natural occuring poplar stands. Under the most inexpensive plantation senario the cost of an oven dry tonne is $53.16 verses $19.12 for a natural stand. Thus indicating that with the current abundance of natural stands the plantation methodology is not a viable proposition.

Suggested changes to the plantation treatments used in this study include utilizing plastic mulch to overcome weed competion and the incorporation of access lanes through the plantation so that agricultural equipment can be used for

fertilizer application and pest control.

In summation, hybrid poplar planting can be successfully grown and produce reasonable amounts of biomass with appropriate input of fertilizer and pest control but are currently are an uneconomic source of biomass.

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APPENDICES

APPENDIX I

NUMBER OF ROOT STOCKS PER PLOT FOR UPTON ROAD SITE

PLOT-CLONE DENSITY-FERTILIZER	ROOT STOCKS/PLOT
1-44-M-4N	112
2-79-H-0N	262
3-44-H-2N	204
4-79-M-4N	149
5-79-L-1N	62
6-44-L-4N	47
7-44-H-4N	250
8-79-L-4N	58
9-44-M-2N	117
10-44-L-0N	49
11-44-M-1N	125
12-79-M-0N	151
13-44-M-0N	158
14-79-H-4N	298
15-79-L-2N	63
16-79-M-2N	156
17-44-H-0N	252
18-79-L-0N	62
19-44-H-1N	266
20-79-H-2N	272
21-44-L-1N	56
22-79-M-1N	158
23-44-L-2N	62
24-79-H-1N	301

NUMBER OF ROOT STOCKS PER PLOT FOR BRISTOL SITE

PLOT-CLONE-DESITY-FERTILIZER	ROOT STOCKS/PLOT
1-79-L-4N	35
2-44-H-0N	195
3-79-H-4N	146
4-79-L-2N	41
5-79-H-2N	231
6-79-M-4N	106
7-44-L-4N	34
8-44-M-1N	114
9-79-L-1N	59
10-79-H-0N	257
11-44-H-4N	222
12-44-M-4N	73
13-79-H-1N	244
14-79-M-2N	110
15-44-H-1N	180
16-44-L-2N	25
17-44-H-2N	145
18-44-M-2N	103
19-44-M-0N	121
20-79-M-0N	96
21-44-L-1N	19
22-79-M-1N	91
23-44-L-0N	41
24-79-L-0N	54

APPENDIX II

HEIGHT/DIAMETER COEFFICIENTS FOR THE UPTON ROAD SITE

PLOT #	#SAMPLES	COEFFICENTS a	b	R2
1	90	3.64025	10.4872	.92124
2	90	7.20526	11.2557	.839625
3	72	2.43141	12.6394	.705365
4	122	-1.71474	15.7014	.857750
5	173	-8.17869	15.0936	.814235
6	117	3.92198	10.0799	.831478
7	41	-8.2516	14.1358	.92900
8	214	11.6141	12.9941	.744264
9	81	5.6373	10.5915	.809502
10	192	6.83793	10.7864	.811270
11	135	-2.05823	12.0478	.948404
12	209	-3.04754	14.2049	.873343
13	154	1.42643	10.4128	.741007
14	93	.788359	17.0283	.822083
15	225	-8.21409	16.1089	.826286
16	161	12.6304	13.878	.811991
17	58	23.5976	7.17877	.726624
18	250	-6.45381	14.1886	.841211
19	53	3.24985	11.7782	.848711
20	50	33.7174	10.032	.738046
21	178	19.7087	9.22595	.768863
22	83	1.87446	13.1586	.823271
23	118	20.0947	10.3558	.695260
24	56	28.4445	11.3896	.638821

* EQUATION : HEIGHT = a + b (DIAMETER)

HEIGHT/DIAMETER COEFFICIENTS FOR THE BRISTOL SITE

PLOT#	#SAMPLES	COEFFICENTS a	b	R2
1	17	11.7393	7.03995	.79727
2	52	-.442524	11.0941	.92445
3	21	9.90541	11.3538	.96185
4	70	30.3804	7.73526	.80187
5	62	26.1334	11.2777	.75833
6	85	23.2625	9.7101	.85540
7	31	15.8689	7.6342	.94199
8	51	33.155	8.59198	.8690
9	60	18.9942	9.42266	.81862
10	51	-6.73225	13.8235	.89567
11	28	17.7276	9.82693	.74143
12	31	21.1754	9.26438	.94275
13	55	43.8211	9.8655	.73474
14	37	26.399	10.0618	.86690
15	39	32.9367	8.56435	.68213
16	23	34.4337	4.77073	.77205
17	28	21.8245	8.80146	.77985
18	47	10.8009	9.60148	.87730
19	49	15.9808	9.51334	.87589
20	54	58.4444	7.32397	.75902
21	26	1.35673	9.90647	.88573
22	50	10.9222	12.3215	.85114
23	30	12.0832	9.0574	.73009
24	88	5.47372	11.8199	.78014

* EQUATION : HEIGHT = a + b (DIAMETER)

APPENDIX III

SOIL ANALYSIS RESULTS FOR UPTON ROAD SITE BEFORE GROWING SEASON

Plot-Clone-Density-Fertilizer	pH	Phosphate (ppm)	Potash (ppm)	Calcium (ppm)	Magnesium (ppm)	Nitrogen (%)
1-44-M-4N	5.3	108	107	190	32	13
2-79-H-0N	5.6	114	119	242	51	13
3-44-H-2N	5.5	100	103	192	34	13
4-79-M-4N	5.4	142	76	104	20	14
5-79-L-1N	5.7	106	100	220	43	13
6-44-L-4N	5.5	106	98	194	28	12
7-44-H-4N	5.5	90	82	182	27	9
8-79-L-4N	5.5	112	104	182	30	9
9-44-M-2N	5.7	134	151	276	60	9
10-44-L-0N	5.9	96	138	300	73	9
11-44-M-1N	5.7	88	120	254	54	9
12-79-M-0N	5.8	120	122	262	59	10
13-44-M-0N	5.9	136	140	288	64	9
14-79-H-4N	5.7	146	82	168	31	9
15-79-L-2N	5.8	104	106	249	50	9
16-79-M-2N	5.8	80	102	242	52	11
17-44-H-0N	5.8	128	139	232	54	13
18-79-L-0N	5.8	140	99	210	49	11
19-44-H-1N	5.6	128	111	224	46	11
20-79-H-2N	5.6	124	105	186	37	11
21-44-L-1N	5.7	120	102	220	57	12
22-79-M-1N	5.6	142	108	243	45	12
23-44-L-2N	5.7	140	115	260	48	11
24-79-H-1N	6.0	110	120	388	61	12

* Average of 2 samples

1-44-M-4N
1-plot #
44-clone #
M-root stock density
4N-400kg/ha Nitrogen

SOIL ANALYSIS RESULTS FOR BRISTOL SITE BEFORE GROWING SEASON

Plot-Clone-Density-Fertilizer	pH	Phosphate (ppm)	Potash (ppm)	Calcium (ppm)	Magnesium (ppm)	Nitrogen (%)
1-79-L-4N	5.9	106	133	314	57	14
2-44-H-0N	6.7	56	152	535	148	14
3-79-H-4N	6.0	64	154	404	80	15
4-79-L-2N	6.5	62	166	526	126	15
5-79-H-2N	6.5	68	172	510	104	15
6-79-M-4N	5.9	60	146	320	54	18
7-44-L-4N	6.1	100	176	456	74	17
8-44-M-1N	6.6	80	172	545	140	17
9-79-L-1N	6.6	78	177	494	130	17
10-79-H-0N	6.7	84	157	510	131	15
11-44-H-4N	5.9	66	150	325	58	13
12-44-M-4N	5.8	62	155	356	54	12
13-79-H-1N	6.2	68	149	478	126	12
14-79-M-2N	6.3	150	170	560	127	11
15-44-H-1N	6.4	286	153	496	126	11
16-44-L-2N	6.4	266	202	572	127	12
17-44-H-2N	6.4	194	157	520	106	10
18-44-M-2N	6.2	84	150	370	80	11
19-44-M-0N	6.8	348	151	720	184	9
20-79-M-0N	6.7	276	218	675	162	14
21-44-L-1N	6.4	158	186	563	161	15
22-79-M-1N	6.7	154	178	578	158	15
23-44-L-0N	6.7	216	182	708	192	14
24-79-L-0N	6.8	206	165	648	179	14

* Average of 2 samples.

SOIL ANALYSIS FOR UPTON ROAD SITE AFTER THE GROWING SEASON

Plot-Clone-Density-Fertilizer	pH	Phosphate (ppm)	Potash (ppm)	Calcium (ppm)	Magnesium (ppm)	Nitrogen (%)
1-44-M-4N	4.8	7	104	149	29	11
2-79-H-0N	5.5	6	124	241	49	12
3-44-H-2N	5.6	6	136	262	53	10
4-79-M-4N	5.1	9	103	132	30	12
5-79-L-1N	5.4	8	99	173	38	12
6-44-L-4N	4.5	24	104	103	18	14
7-44-H-4N	5.2	10	98	135	30	12
8-79-L-4N	4.6	21	99	104	18	14
9-44-M-2N	5.2	11	145	222	42	12
10-44-L-0N	5.6	7	121	262	57	12
11-44-M-1N	5.4	10	132	243	47	16
12-79-M-0N	4.9	18	110	88	28	13
13-44-M-0N	5.5	11	113	253	48	12
14-79-H-4N	5.4	7	129	230	43	12
15-79-L-2N	5.6	8	122	351	64	12
16-79-M-2N	5.6	10	114	291	60	13
17-44-H-0N	5.6	11	161	312	65	9
18-79-L-0N	5.6	11	134	291	60	12
19-44-H-1N	5.4	11	99	246	50	12
20-79-H-2N	5.4	10	130	272	54	14
21-44-L-1N	5.5	9	123	273	54	12
22-79-M-1N	5.5	9	127	332	52	13
23-44-L-2N	5.6	26	124	288	50	13
24-79-H-1N	5.6	9	169	404	63	13

* Average of 2 samples

SOIL ANALYSIS RESULTS FOR BRISTOL SITE AFTER GROWING SEASON

Plot-Clone-Density-Fertilizer	pH	Phosphate (ppm)	Potash (ppm)	Calcium (ppm)	Magnesium (ppm)	Nitrogen (%)
1-79-L-4N	5.6	13	96	284	44	12
2-44-H-0N	6.6	8	133	504	136	9
3-79-H-4N	5.6	12	122	294	45	10
4-79-L-2N	6.4	9	102	426	100	9
5-79-H-2N	6.2	8	108	483	98	11
6-79-M-4N	5.2	12	92	254	36	11
7-44-L-4N	5.7	19	180	638	67	15
8-44-M-1N	6.5	8	101	516	134	12
9-79-L-1N	6.2	10	117	384	98	10
10-79-H-0N	6.5	10	122	499	135	11
11-44-H-4N	5.3	12	79	226	32	10
12-44-M-4N	5.4	8	89	256	38	13
13-79-H-1N	6.3	9	106	430	113	12
14-79-M-2N	6.1	8	104	409	88	12
15-44-H-1N	6.2	11	90	413	98	11
16-44-L-2N	6.3	9	119	498	106	12
17-44-H-2N	6.1	8	106	347	67	12
18-44-M-2N	5.8	9	104	343	64	11
19-44-M-0N	6.3	16	189	684	130	16
20-79-M-0N	6.3	14	192	670	115	17
21-44-L-1N	6.4	6	109	467	137	12
22-79-M-1N	6.2	15	174	647	109	17
23-44-L-0N	6.7	7	134	612	177	13
24-79-L-0N	6.3	14	180	649	113	16

* Average of 2 samples.

APPENDIX IV

NUTRIENT ANALYSIS FOR UPTON ROAD, STEMS

	%N	%P	%K	%Ca	%Mg
1-44-M-4N	0.7	.09	.68	.27	.13
2-79-H-0N	0.7	.08	.50	.29	.14
3-44-H-2N	0.7	.11	.69	.24	.11
4-79-M-4N	0.8	.10	.56	.26	.11
5-79-L-1N	0.6	.10	.46	.36	.13
6-44-L-4N	0.7	.08	.50	.36	.14
7-44-H-4N	0.5	.08	.61	.40	.14
8-79-L-4N	0.7	.11	.52	.30	.11
9-44-M-2N	0.6	.10	.62	.28	.12
10-44-L-0N	0.4	.11	.47	.31	.14
11-44-M-1N	0.9	.14	.59	.33	.17
12-79-M-0N	0.6	.11	.59	.28	.14
13-44-M-0N	0.7	.12	.47	.35	.15
14-79-H-4N	0.8	.11	.60	.24	.11
15-79-L-2N	0.6	.10	.52	.27	.10
16-79-M-2N	0.7	.09	.56	.35	.13
17-44-H-0N	0.9	.10	.50	.39	.18
18-79-L-0N	0.7	.11	.62	.43	.19
19-44-H-1N	0.8	.11	.64	.32	.16
20-79-H-2N	0.8	.07	.51	.24	.11
21-44-L-1N	0.6	.08	.45	.29	.11
22-79-M-1N	0.6	.10	.46	.26	.11
23-44-L-2N	0.7	.08	.53	.28	.14
24-79-H-1N	0.6	.08	.50	.36	.10

NUTRIENT ANALYSIS FOR BRISTOL, STEMS

	%N	%P	%K	%Ca	%Mg
1-79-L-4N	0.7	.08	.41	.35	.11
2-44-H-0N	0.8	.15	.54	.49	.21
3-79-H-4N	0.8	.07	.43	.33	.09
4-79-L-2N	0.6	.09	.35	.35	.10
5-79-H-2N	0.5	.05	.43	.27	.08
6-79-M-4N	0.5	.08	.40	.35	.09
7-44-L-4N	0.6	.05	.36	.32	.12
8-44-M-1N	0.7	.11	.46	.47	.15
9-79-L-1N	0.7	.06	.44	.45	.05
10-79-H-0N	1.3	.15	.57	.57	.24
11-44-H-4N	0.8	.15	.59	.51	.20
12-44-M-4N	0.7	.10	.60	.47	.15
13-79-H-1N	0.5	.10	.40	.31	.09
14-79-M-2N	0.7	.11	.50	.40	.11
15-44-H-1N	0.6	.11	.43	.37	.14
16-44-L-2N	0.7	.09	.46	.41	.14
17-44-H-2N	0.6	.10	.35	.39	.15
18-44-M-2N	0.8	.10	.49	.40	.15
19-44-M-0N	0.8	.14	.49	.58	.20
20-79-M-0N	0.5	.08	.42	.40	.10
21-44-L-1N	0.7	.08	.44	.35	.14
22-79-M-1N	0.6	.09	.53	.50	.18
23-44-L-0N	0.7	.06	.42	.44	.16
24-79-L-0N	0.6	.08	.47	.45	.12

TISSUE ANALYSIS FOR LEAVES,
UPTON ROAD AND BRISTOL, NITROGEN ONLY

Hurry Road Code	%N	Bristol Code	%N
1-44-M-4N	2.3	1-79-L-4N	2.2
2-79-H-0N	1.8	2-44-H-0N	1.4
3-44-H-2N	2.6	3-79-H-4N	2.2
4-79-M-4N	2.3	4-79-L-2N	2.2
5-79-L-1N	1.6	5-79-H-2N	2.2
6-44-L-4N	1.6	6-79-M-4N	2.2
7-44-H-4N	1.9	7-44-L-4N	2.0
8-79-L-4N	2.5	8-44-M-1N	1.7
9-44-M-2N	2.1	9-79-L-1N	2.0
10-44-L-0N	1.6	10-79-H-0N	2.0
11-44-M-1N	1.9	11-44-H-4N	1.9
12-79-M-0N	1.7	12-44-M-4N	2.0
13-44-M-0N	1.7	13-79-H-1N	1.8
14-79-H-4N	2.3	14-79-M-2N	2.2
15-79-L-2N	2.1	15-44-H-1N	1.9
16-79-M-2N	2.7	16-44-L-2N	1.9
17-44-H-0N	1.7	17-44-H-2N	1.8
18-79-L-0N	1.7	18-44-M-2N	1.9
19-44-H-1N	1.8	19-44-M-0N	1.4
20-79-H-2N	2.3	20-79-M-0N	1.7
21-44-L-1N	1.6	21-44-L-1N	2.0
22-79-M-1N	1.9	22-79-M-1N	2.3
23-44-L-2N	1.8	23-44-L-0N	1.5
24-79-H-1N	2.2	24-79-L-0N	1.6

APPENDIX V

GREEN LEAF COEFFICIENTS FOR THE UPTON ROAD SITE

PLOT #	Coefficients a	b	R2
1	8.39840	.21871	.94954
2	9.92232	.21129	.64912
3	4.88128	.13540	.90715
4	0.0	.21327	.93653
5	4.80641	.25726	.74778
6	6.52407	.24332	.78782
7	1.08058	.23776	.73612
8	3.91715	.19118	.91303
9	3.32908	.23227	.85373
10	11.48159	.42128	.88614
11	12.86112	.18290	.83099
12	4.52707	.23990	.59542
13	14.35859	.1827	.56100
14	0.0	.32110	.85284
15	1.57879	.24173	.94823
16	2.91630	.16527	.87325
17	7.28952	.29112	.83520
18	1.59843	.24196	.73946
19	9.22308	.17413	.68390
20	3.76344	.20647	.78385
21	8.03541	.30871	.93245
22	6.22484	.18770	.47173
23	11.47567	.23452	.92183
24	1.32468	.23652	.91836

* EQUATION : WEIGHT = a+bHEIGHT(DIAMETER**2)

GREEN STEM COEFFICIENTS FOR UPTON ROAD SITE

PLOT#	Coefficients a	b	R2
1	6.70369	.30029	.99185
2	3.03086	.36176	.98154
3	1.70483	.31681	.99575
4	0.0	.33740	.98568
5	1.31910	.35351	.98464
6	4.46609	.20712	.78424
7	1.75185	.32426	.98617
8	6.59997	.31643	.96820
9	2.61679	.29631	.98473
10	4.77571	.41806	.95035
11	5.77614	.30515	.95759
12	2.43055	.42233	.91543
13	7.05433	.26689	.71632
14	0.0	.23022	.91755
15	.94373	.37386	.98895
16	2.93052	.35444	.93907
17	1.45626	.40327	.98971
18	.83863	.37754	.92155
19	3.53524	.32559	.97211
20	1.16008	.37184	.98608
21	3.43771	.32246	.98455
22	2.02749	.36681	.86171
23	3.01551	.32196	.9888
24	1.60956	.38873	.97534

* EQUATION : WEIGHT = a+bHEIGHT(DIAMETER**2)

GREEN TOTAL COEFFICIENTS FOR UPTON ROAD SITE

Plot #	Coefficients a	b	R2
1	15.10209	.51899	.98336
2	12.95318	.57305	.89440
3	6.58611	.45221	.99185
4	0.0	.55067	.97424
5	6.12551	.61077	.94627
6	10.99016	.45044	.79046
7	2.83243	.56202	.93476
8	10.51711	.50761	.95656
9	5.94587	.52858	.94312
10	16.25730	.83934	.92254
11	18.63726	.48805	.92930
12	6.95762	.66223	.84655
13	21.41292	.44906	.66454
14	0.0	.55132	.92547
15	2.52252	.61559	.98204
16	5.84682	.51971	.92426
17	8.74577	.69439	.95424
18	2.43706	.61951	.89348
19	12.75851	.49972	.93701
20	4.92352	.57831	.94644
21	11.47312	.63117	.96963
22	8.25233	.55451	.76928
23	14.49119	.55648	.97327
24	2.93424	.62525	.96062

* EQUATION : WEIGHT = a+bHEIGHT(DIAMETER**2)

DRY LEAF COEFFICIENTS FOR UPTON ROAD SITE

Plot #	Coefficients a	b	R2
1	4.03081	.080453	.93086
2	3.30366	.092717	.77404
3	1.90073	.065998	.94436
4	0.0	.08163	.92310
5	2.04435	.10319	.61467
6	3.14823	.085371	.79692
7	1.49247	.077866	.54506
8	2.38440	.063903	.82921
9	1.91378	.071852	.80337
10	4.25528	.13794	.84893
11	5.12986	.059554	.72217
12	1.72293	.10606	.60653
13	6.37052	.060747	.46497
14	0.0	.009152	.88030
15	.78658	.082780	.94652
16	.87465	.059724	.79142
17	1.84981	.10430	.83997
18	.82338	.096718	.72105
19	2.75286	.068896	.73756
20	1.24252	.063063	.78430
21	3.14658	.097011	.87735
22	2.25745	.061867	.55241
23	4.18356	.083653	.86369
24	.44200	.069825	.91126

* EQUATION : HEIGHT = a+bHEIGHT(DIAMETER**2)

DRY STEM COEFFICIENTS FOR UPTON ROAD SITE

Plot #	Coefficients a	b	R2
1	2.90566	.10963	.98179
2	1.45534	.16716	.98449
3	1.13446	.11194	.99146
4	0.0	.15730	.98594
5	1.07627	.16431	.96707
6	2.06462	.098276	.79600
7	.92500	.13251	.96044
8	2.78154	.14664	.96718
9	1.09691	.11883	.95418
10	2.36717	.18576	.93601
11	2.43776	.12916	.95714
12	1.06168	.21358	.92337
13	3.85256	.13065	.73482
14	0.0	.18334	.83595
15	.61250	.17752	.98671
16	1.80550	.14553	.95830
17	.77414	.18300	.98461
18	.39701	.18698	.91123
19	1.69528	.14174	.97121
20	1.09912	.17741	.93496
21	1.50677	.15097	.97138
22	.87501	.17630	.86449
23	1.60540	.14534	.98595
24	.68218	.18052	.96260

* EQUATION : WEIGHT = a+bHEIGHT(DIAMETER**2))

DRY TOTAL COEFFICIENTS FOR UPTON ROAD SITE

Plot #	a	b	R2
1	6.93647	.19008	.96689
2	4.75900	.25988	.93968
3	3.03519	.17794	.988.0
4	0.0	.23893	.97474
5	3.12061	.26750	.93427
6	5.21286	.18365	.80719
7	2.41747	.21038	.85827
8	5.16593	.21054	.94285
9	3.01068	.19068	.92049
10	6.62245	.32370	.90362
11	7.56761	.18871	.90534
12	2.78461	.31964	.86361
13	10.22307	.19140	.66672
14	0.0	.27486	.89393
15	1.39907	.26030	.98259
16	2.68015	.20526	.95121
17	2.62395	.28729	.96333
18	1.22039	.28370	.89747
19	4.44814	.21064	.95188
20	2.34164	.24047	.92883
21	4.65334	.24798	.95452
22	3.13246	.23816	.83366
23	5.78896	.22899	.96482
24	1.12418	.25035	.95363

* EQUATION = WEIGHT = a+bHEIGHT(DIAMETER**2))

GREEN LEAF COEFFICIENTS FOR BRISTOL SITE

Plot #	Coefficients a	b	R2
1	0.0	.44012	.90744
2	1.27171	.15823	.67243
3	0.0	.17892	.76973
4	0.0	.28896	.79638
5	0.0	.09957	.95090
6	0.0	.20614	.68610
7	9.87992	.196050	.61447
8	2.31182	.10371	.68132
9	3.72569	.19278	.59846
10	0.0	.12261	.96479
11	0.0	.18782	.73457
12	1.18100	.26100	.71874
13	3.81184	.029876	.26039
14	0.0	.14634	.53748
15	1.28446	.14918	.72523
16	0.0	.50092	.89922
17	7.90614	.26687	.18020
18	.78638	.28434	.48703
19	5.34665	.10599	.65330
20	.88941	.063311	.50468
21	14.43414	.23121	.86729
22	6.62187	.10520	.28456
23	3.58490	.35246	.68219
24	0.0	.20345	.78928

* EQUATION : WEIGHT = a+bHEIGHT(DIAMETER**2)

GREEN STEM COEFFICIENTS FOR BRISTOL SITE

	Coefficients a	b	R2
1	0.0	.74004	.96491
2	.81383	.39535	.92878
3	0.0	.42954	.96319
4	0.0	.56190	.93320
5	0.0	.39041	.96950
6	0.0	.47199	.96511
7	9.33935	.39482	.87567
8	1.87659	.38517	.99795
9	1.58746	.42479	.97170
10	0.0	.38199	.99337
11	0.0	.34177	.94912
12	7.55310	.34371	.96583
13	26.12706	.11483	.29515
14	0.0	.46023	.90719
15	3.78078	.36343	.98080
16	0.0	.57142	.96749
17	8.35706	.41659	.29849
18	17.83976	.33536	.32426
19	5.31889	.38842	.97649
20	1.08066	.45798	.90531
21	15.07518	.36144	.97986
22	7.38016	.37044	.55491
23	2.41064	.52693	.91734
24	0.0	.52435	.65213

* EQUATION : WEIGHT = a+b Height(Diameter**2))

GREEN TOTAL COEFFICIENTS FOR BRISTOL SITE

Plot #	Coefficients a	b	R2
1	0.0	1.18016	.95338
2	2.08555	.55358	.91795
3	0.0	.60845	.95319
4	0.0	.85086	.90778
5	0.0	.48998	.97876
6	0.0	.67813	.90930
7	19.21928	.59088	.80424
8	4.18842	.48887	.97652
9	5.31315	.61757	.90278
10	0.0	.50461	.99202
11	0.0	.52959	.90809
12	8.73409	.60470	.89980
13	29.93889	.14470	.29237
14	0.0	.60657	.87367
15	5.06524	.51261	.93985
16	0.0	1.07235	.96280
17	16.26319	.68347	.24560
18	18.62614	.61969	.41010
19	10.66553	.49442	.94376
20	1.97006	.52129	.88553
21	29.50931	.59265	.96044
22	14.00203	.47564	.59639
23	5.99553	.87939	.87558
24	0.0	.72779	.77562

* EQUATION : W = a+bHEIGHT(Diameter**2))

DRY LEAF COEFFICIENTS FOR BRISTOL SITE

Plot #	Coefficients a	b	R2
1	0.0	.17619	.91657
2	.73663	.069306	.60767
3	0.0	.07410	.61449
4	0.0	.12640	.79255
5	0.0	.05053	.95386
6	0.0	.09699	.70154
7	4.98409	.096668	.65384
8	1.09316	.035439	.64277
9	1.87310	.071749	.68559
10	0.0	.05176	.91086
11	0.0	.07759	.56673
12	1.86493	.10097	.64638
13	1.45871	.010925	.24667
14	0.0	.05421	.52887
15	.19316	.051423	.77390
16	0.0	.18212	.89479
17	3.94384	.092601	.14516
18	.69891	.10425	.49193
19	2.56878	.040498	.52155
20	.25857	.033449	.65065
21	5.23541	.096175	.82554
22	3.11778	.041144	.27257
23	1.47444	.15586	.70948
24	0.0	.09740	.79899

* EQUATION : W = a+bHEIGHT(DIAMETER**2))

DRY STEM COEFFICIENTS FOR BRISTOL SITE

Plot #	Coefficients a	b	R2
1	0.0	.39217	.96150
2	.38949	.19571	.95260
3	0.0	.21400	.96612
4	0.0	.28385	.92624
5	0.0	.19312	.95768
6	0.0	.25291	.95245
7	5.04699	.20785	.83029
8	.50127	.18134	.99312
9	.36479	.21366	.97589
10	0.0	.20463	.99167
11	0.0	.16269	.80060
12	2.81898	.17381	.95152
13	12.92652	.058091	.29345
14	0.0	.23593	.90492
15	2.11629	.18054	.96426
16	0.0	.28512	.97331
17	4.88274	.20454	.25907
18	7.48229	.15867	.34115
19	2.83759	.18975	.96796
20	.47292	.23135	.89140
21	7.83243	.16345	.95824
22	3.16051	.18274	.55390
23	.90167	.26473	.91603
24	0.0	.25357	.57267

* EQUATION : W = a+bHEIGHT(DIAMETER**2))

DRY TOTAL COEFFICIENTS FOR BRISTOL SITE

Plot #	Coefficients a	b	R2
1	0.0	.56836	.95509
2	1.12612	.26502	.92129
3	0.0	.28810	.93813
4	0.0	.41025	.91041
5	0.0	.24365	.97480
6	0.0	.34991	.91831
7	10.03107	.30452	.78557
8	1.59443	.21678	.98346
9	2.23789	.28541	.95018
10	0.0	.25639	.98963
11	0.0	.24028	.81040
12	4.68391	.27478	.89281
13	14.38523	.069015	.29147
14	0.0	.29014	.88682
15	2.30945	.23196	.94890
16	0.0	.46724	.96952
17	8.82658	.29714	.22541
18	8.18120	.26292	.41758
19	5.40636	.23025	.92809
20	.73149	.2622389	.57682
23	2.37611	.42059	.88644
24	0.0	.35097	.73243

* EQUATION : W = a+bHEIGHT(DIAMETER**2))